Exploring the Processing Continuum of Single-Word Comprehension in Aphasia

THEORETICAL/REVIEW ARTICLE

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This study investigated the vulnerability of lexical processing in individuals with aphasia. Though classical teaching of aphasia syndromes holds that people with Broca's aphasia have intact comprehension at the single-word level, the nature and extent of this purported sparing were explored under suboptimal processing conditions. A combination of acoustic distortions (low-pass filtering and time compression) was used to probe for ''break points'' in lexical comprehension in a group of individuals with aphasia. Results suggest that accurate and efficient lexical processing is vulnerable to suboptimal listening climates, and that processing under these conditions reveals the continuous nature of the impairment of linguistic behaviors observed in individuals with aphasia.

KEY WORDS: Broca's aphasia, language comprehension, auditory comprehension, aphasia

Mapping out the specific deficits and the underlying mechanisms responsible for language breakdown has been a chief endeavor of aphasiologists since the late-19th century. Although we have accumulated a wealth of empirical evidence over the past century that has broadened and refined our knowledge of aphasia, our definitions and descriptions of the various aphasia subtypes have remained fairly modular. The various syndromes are typically viewed as dissociations in either modality of processing (e.g., production vs. comprehension) or level of linguistic breakdown (e.g., grammatical vs. lexical). There is an abundance of data, however, that suggests that such discrete dissociations are rather rare, leading scientists to consider that the deficits in aphasia may be more continuous in nature. Since the time of Freud (1891/1953), there has been an abundance of alternate accounts for the breakdown seen in individuals with aphasia, including deficits in attention allocation, processing capacity, and verbal working memory (Caplan & Waters, 1995; Just & Carpenter, 1992; Linebarger, Schwartz, & Saffran, 1983; McNeil, 1981). Such accounts presume that deficits in nonlinguistic functions (imposed by either endogenous conditions or exogenous factors) may also play an important role in the breakdowns observed in language processing.

As such, it would seem important to incorporate these findings into textbook descriptions, theories, treatment, and thought of aphasic syndromes for several reasons. First, it is essential to outline the full array of behaviors observed in a patient population in order to formulate an accurate and useful model or theory of aphasia. Although some features

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of a disorder may be more prominent (e.g., grammatical deficits are more evident in individuals with Broca's aphasia [BA] than are lexical deficits), the picture of the disorder is incomplete without the other components. Second, in not including some of the finer details that we have discovered over the years, we may be inadvertently overlooking certain features of the deficit that may be important during treatment and for the ultimate functional outcome of our patients.

This article aims to provide support for rethinking and redefining the symptom space in aphasia syndromes to reflect the continuous nature of the deficits. Specifically, we present data that we feel challenge one particular claim that has been made about individuals with BA, namely, that they have intact single-word comprehension (Goodglass, 1968; Goodglass & Kaplan, 1983; Schwartz, Saffran, & Marin, 1980). We attempt to demonstrate that accurate and efficient processing in the linguistic domain is highly contingent on the availability of general cognitive resources and the processing climate. Furthermore, this claim not only applies to the processing profile of individuals with aphasia but extends to normal, healthy adults as well.

Lexical Processing in BA

Historically, BA has been described as a deficit in speech production, with the preservation of comprehension skills (Broca, 1861). In the latter half of the 20th century, there was a refinement of this description that shifted the focus of attention from a modality-based disorder to a content-based disorder. Hence, given that production is obviously more impaired than comprehension in BA, the heart of the problem appeared to lie in the processing of grammatical features, independent of modality, with a sparing of lexical processing (Berndt & Caramazza, 1999; Caramazza & Zurif, 1976; Geschwind, 1970; Goodglass, 1993; Goodglass & Kaplan, 1983). To date, these features remain a hallmark of BA. Empirical evidence over the past two decades has, however, provided strong support that lexical processing, while superior to grammatical processing, is not universally spared in individuals with BA.

In the early 1980s, several researchers set out to investigate online lexical access in BA; (Blumstein, Milberg, & Shreir, 1982; Hagoort, 1990, 1997; Milberg & Blumstein, 1981; Milberg, Blumstein, & Dworetzky, 1987; Milberg, Blumstein, Katz, Gershberg, & Brown, 1995; Milberg, Sullivan, & Blumstein, 1998; Prather, Zurif, Love, & Brownell, 1997; Prather, Zurif, Stern, & Rosen, 1992; Swinney, Zurif, & Nicol, 1989; Utman, Blumstein, & Sullivan, 2001). Patients were administered various priming tasks in which patients' ability to retain semantic relationship between pairs of words was tested. Whereas some individuals with BA do show evidence of normal priming under some conditions (Blumstein et al., 1982; Hagoort, 1990, 1997), there are reports of others failing to prime under different conditions (Milberg & Blumstein, 1981; Milberg et al., 1987; Prather et al., 1992, 1997; Swinney et al., 1989; Utman et al., 2001). The majority of the evidence suggests that individuals with BA demonstrate reduced and/or delayed activation of lexical items in comparison to normal controls and to individuals with Wernicke's aphasia (WA; Milberg et al., 1987; Prather et al., 1992, 1997; Swinney et al., 1989).

Whereas online lexical access has been shown to be disrupted in many individuals with BA, the integrity of single-word comprehension in BA has not been seriously challenged. In fact, most researchers report that individuals with BA show failures at the sentence level in the context of spared or normal comprehension of isolated words (Berndt & Caramazza, 1999; Caramazza & Zurif, 1976; Goodglass & Kaplan, 1983), without always testing comprehension at the single-word level. This may be for obvious reasons: Individuals with BA, time and again, perform well within normal limits on off-line single-word comprehension tasks—thus leading to the conclusion that this function is intact. Can vulnerabilities in single-word comprehension be revealed, however, when the task demands are changed? Research at both the grammatical and lexical levels has shown that performance is highly dependent on the nature of the task. It is therefore reasonable to consider that even comprehension of single words may be graded in individuals with BA in varying contexts.

The present study draws on growing evidence suggesting that certain aspects of performance by patients with aphasia (including BA) can be simulated in healthy young adults who are forced to process linguistic stimuli under degraded processing conditions. A profile resembling performance by patients with aphasia on the same tasks has been demonstrated in several studies of receptive grammar (Blackwell & Bates, 1995; Dick et al., 2001; Kilborn, 1991). These studies provide support that deficits in grammar may reflect processing restrictions that are not specific to morphosyntax, or to language in general.

Acoustic degradation, including low-pass filtering and time compression, has also been used to investigate breakdown at the lexical level (Aydelott & Bates, 2004; Utman & Bates, 1998). In these studies, low-pass filtering reduces the amount of information in the spectral signal, thereby simulating age-related hearing decrements. Time compression leaves intact the spectral signal, but taxes the system in processing a greater chunk of information in a shorter amount of time, thereby simulating the often observed cognitive slowdown seen in normal aging and after brain damage. Given these results, it is not surprising that a combination of these stressors can lead to "superadditive" language deficits (i.e., decrements in performance that are greater than the simple sum of the deficits produced from each single factor), resembling those seen in individuals with language disorders (Aydelott & Bates, 2004; Dick et al., 2001; Gordon-Salant & Fitzgibbons, 1995; Harris, 1960; Lacroix, Harris, & Randolph, 1979).

These studies of normals under stress provide indirect evidence for accounts of aphasic deficits based on nonlinguistic aspects of processing. One of the earliest accounts of this sort was offered by McNeil (1981), who suggested that receptive deficits may reflect an attention allocation problem rather than loss of linguistic knowledge. Around the same time, another group of researchers argued that agrammatism was a result of a general reduction in processing capacity (i.e., trade-off theory; Linebarger et al., 1983). Other early accounts predicted that deficits in verbal working memory or an overall reduction in processing resources (Caplan & Waters, 1995, 1999; Just & Carpenter, 1992) could result in the selective deficits that we see in individuals with aphasia. Finally, there are also claims that processing deficits may be due to adaptations to the aberrant output following economy of effort (Kolk & Heeschen, 1992). All of these theories, despite their differences, rest on the assumption (and demonstration) that deficits specific to the domain of language can arise from taxing domain-general mechanisms. To the extent that the performance of neurologically intact individuals subjected to exogenous stressors mirrors (qualitatively, not quantitatively) that of brain-injured patients, it is reasonable to consider that linguistic performance is dependent on availability of general cognitive resources, environmental conditions, and task complexity—and that successful task performance is dependent on the combination of these factors. Because these factors vary from moment to moment within a given individual (given different levels of fatigue, attention, noise, speed of presentation, sentence complexity, and task demands at a particular time), performance may lie on a continuum of intactness, and all structures within the linguistic domain may be vulnerable to such factors and thus susceptible to breakdown.

In the present study, we investigated the vulnerability of single-word comprehension in individuals with BA by putting them and other groups under the stress of performing a lexical verification task (word-picture matching) in a normal and a multiply-degraded condition (a combination of low-pass filtering and time compression). We compared their results to those of nonlesioned elderly controls, right-hemisphere-damaged participants, and individuals with anomic aphasia (AA) and WA. We expected that we would see a graded decrease in accurate and efficient word comprehension based on how classic taxonomies would predict individual groups to be impaired on a word comprehension task. Classic taxonomies would predict the following patterns of performance: (a) Individuals with WA should be more impaired on a single-word comprehension task than individuals with BA, (b) individuals with BA should be more impaired in performance as compared to individuals with AA, (c) individuals with AA should perform worse than individuals with right hemisphere injury, and (d) elderly controls should perform the best overall. Most important for our purposes here, we predicted that this gradient would be most evident (or only evident) with degraded speech.

Method

Participants

Forty-two individuals participated in the current study, including 16 healthy older controls (OCs) with no reported history of neurological damage, 4 individuals with right-hemisphere damage (RHD), and 22 individuals with aphasia. This latter group included 8 individuals classified with AA, 9 with BA, and 5 with WA, as classified by the Western Aphasia Battery (WAB; Kertesz, 1979, 1982). See Table 1 for patient information. Data from 3 additional participants with aphasia were excluded due to an impaired ability to comprehend and perform the task (as determined in the practice session). All participants had normal, or corrected to normal, vision. All OCs were informally assessed, via questionnaire and discussion, for hearing loss. All participants with aphasia were screened for hearing thresholds via audiometric assessment at 20 dB at 500, 1000, 2000, and 4000 Hz bilaterally. Several patients were noted to have mild high-frequency hearing loss (no greater than 35 dB at or above 2000 Hz).[1] All patients with aphasia were screened for etiology of the aphasia—participants with neurological insult resulting from head trauma, tumors, or multiple infarcts were excluded from the study. The OCs were recruited from the greater San Diego and the San Francisco Bay Area communities and were paid for their participation.[2] All other

[1]The low-pass filtering applied to the speech sounds in this experiment eliminated the frequency information above 1000 Hz. Patients with high-frequency loss were thus not excluded, as their hearing in the lower frequencies ranges was noted to be within normal limits on audiometric examination.

[2]This group of controls ranged from 49 to 74 years of age, with no known history of neurological disease. They are referred to here as OCs, as this study was also conducted with younger controls. Although the majority of our patients with aphasia were within the age range of the older adults, there were a few younger individuals with aphasia included in our experiment. Despite the younger age of some of the individuals with aphasia, they, too, were compared to the OCs, as their response times showed similarly long latencies.

Table 1. Participants from the patient population are listed below by age, aphasia type, aphasia classification category, aphasia quotient (AQ), and subtest scores for Comprehension and Fluency as calculated from the Western Aphasia Battery.

Age	Aphasia Type	AQ	Comprehension	Fluency
62	Anomic	92.4	10	9
75	Anomic	98	10	9
56	Anomic	79.2	9.8	5
50	Anomic	93.8	9.7	9
55	Anomic	84.4	8.6	9
66	Anomic	92.2	9.8	9
72	Anomic	88.4	9.5	9
43	Anomic	91.7	9.85	9
76	Broca's	11.2	5	1
50	Broca's	34.6	7.6	2
46	Broca's	49.6	9.3	2
46	Broca's	47.6	6	4
56	Broca's	18.22	6.11	0
24	Broca's	71.6	8.4	4
32	Broca's	68.3	8.65	4
72	Broca's	32.8	6.9	2
70	Broca's	33.4	5.5	2
71	Wernicke's	77.4	6.8	8
50	Wernicke's	78	6.9	9
82	Wernicke's	51.5	6.05	8
74	Wernicke's	33.3	2.05	7
77	Wernicke's	69.8	6.7	8

individuals (individuals with aphasia and RHD participants) were recruited from the Veterans' Administration Medical Centers, San Diego or Martinez, California; the San Diego State University's Communication Disorders Clinic; or the greater San Diego medical community; and they too were paid for their participation. The RHD group, like the participants with aphasia, all suffered a single, unilateral stroke and were used here as an additional comparison group to investigate the effects of acoustic degradation on individuals with brain injury but not aphasia.

Materials and Design

To assess the hypothesis that lexical processing is vulnerable to breakdown in individuals with BA, a word–picture matching task was seen under normal and degraded conditions. Toward this end, a 2 (within-subjects) $\times$ 1 (between-subjects) design was used. The within-subjects factors were congruency (picture and auditory target word were either congruent or incongruent) and alteration (unaltered vs. degraded sound stimuli). The between-subjects variable was participant group (OC, RHD, BA, AA, WA). Both accuracy and reaction times served as dependent variables.

The visual stimuli consisted of 472 black line-drawn pictures of animate and inanimate objects named by common nouns (Abbate & La Chappelle, 1979; Snodgrass & Vanderwart, 1980). An additional set of 8 pictures was used as a practice set. All pictures were optically scanned, edited, and presented on a Macintosh 3400c Powerbook computer using the PsyScope experimental shell from Carnegie Mellon University (Cohen, MacWhinney, Flatt, & Provost, 1993). Auditory stimuli consisted of 472 words (plus 8 additional for the practice set) that corresponded to the dominant names given to the picture stimuli, as determined in a separate norming study. Words were recorded onto a digital audiotape using a Sony Digital Audio Tape recorder and a high-quality condenser microphone in a sound-proof booth. The recordings were then digitized onto a Macintosh computer using SoundDesigner II (Digidesign, 1994) software, at a sampling rate of 44.10 kHz. The stimuli were edited for presentation in both an unaltered and an acoustically degraded condition. A combination of degradations was used in an attempt to investigate the effects of both peripheral and central disturbances on the processing of acoustic signals (i.e., the acoustic manipulations were low-pass filtered at 1 kHz and 50% time compression). These levels of distortion were based on extensive pilot work (and several completed studies) in our laboratories demonstrating that each of these levels (together and separately) significantly affects both accuracy and reaction times for auditory words and sentences (e.g., Aydelott & Bates, 2004; Dick et al., 2001). The distortions were implemented using the equalizer and tempo functions in the Sound-Edit 16 (Macromedia, 1995) software package. The original sound files were first filtered by running them through the equalizer twice at 1 kHz. Once the filtering was complete, the stimuli were then compressed, using the tempo function, to 50% of their original rate.

A picture–word verification task was designed, using the stimuli across four conditions: (congruent–unaltered, congruent–altered, incongruent–unaltered, and incongruent–altered), thus manipulating the congruency of words and pictures and the alteration of the auditory stimuli. *Congruency* refers to a presentation in which the presented sound stimuli accurately matches, or names, the presented picture stimuli. An incongruent trial is therefore a trial in which the sound stimuli presented does not accurately match, or name, the presented picture stimuli. Classification as incongruent was based on an assessment of semantic relatedness. Stimuli were checked for semantic relatedness by using a measure of latent semantic analysis (LSA). This index assigns greater percentage scores to items that are considered highly related and lower percentage scores to items that are considered quite unrelated. LSA is a measure that can be used freely by accessing http://lsa.colorado.edu (please refer to the Web site for an explanation of how the measure is computed). In the current study, items were classified as incongruent if their correlation was $< .20$. The experiment was designed to completely counterbalance presentation of stimuli across all within-subject experimental conditions. A total of four lists were created, each containing all 472 picture and sound stimuli, so that all participants were presented with all experimental stimuli but were presented with each item only once (i.e., stimuli were not repeated during the experiment). The 472 items were broken down into four blocks of 118 items in each of the four experimental conditions. Items appearing in Condition 1 in List 1 appeared in Condition 2 in List 2, and so on, in order to counterbalance items over conditions. Items were then selected and presented in random order from the lists as generated by the PsyScope script.

Procedure

Participants were seated in front of a VGA monitor, speakers and a standard PsyScope button box. The PsyScope button box had three buttons of different colors. Only the right- and left-most buttons were used in this experiment. The buttons have a smiley face or a frowning face placed above them in order to indicate a match or mismatch. The participants were given instructions and then a practice session, after which they could ask questions of clarification.

The experiment consisted of 472 experimenter-advanced trials. A trial consisted of the simultaneous presentation of one of the pictures of the common objects, on the screen, and one of the spoken sound stimuli. Participants were asked to indicate whether or not the spoken word accurately matched the visually presented picture by pressing one of two buttons on the PsyScope button box. Counterbalancing of happy and sad face placement was done so that 50% of participants had the happy face on the left and the sad face on the right, and the other 50% had the reverse pattern. Participants were instructed to answer as quickly and accurately as possible as both reaction time and accuracy were being recorded for each trial.

Scoring

Accuracy was calculated as percentage correct in each of the four conditions (congruent–unaltered, congruent–altered, incongruent–unaltered, incongruent–altered). Response time analyses were restricted to those items on which participants made a correct response. Reaction times were calculated from the beginning of the auditory word.

Results

Results are reported for (a) participants with brain injuries (individuals with both RHD and aphasia) compared to older controls, and (b) aphasic participants only (aphasic group differences as well as correlational analyses examining the contribution of continuous variables from the WAB on performance within and across conditions). Because of the small sample size in each group and the need to counterbalance stimuli across participants, there were not enough data to do an analysis over items. The results for accuracy and reaction time are therefore solely reported over participants. For these analyses, data were entered into separate spreadsheets, and analyses of variance (ANOVAs) were conducted. Unless otherwise specified, all ANOVAs were carried out with SuperAnova and JMPIN 3.1 (SAS Institute, 1996), and all pairwise comparison values were Bonferroni adjusted. For significant main effects and interactions, the effect size η_p^2 (partial eta squared) was calculated. The error bars on the figure reflect ±1 standard error of the mean.

Participants With Brain Injuries and OCs

To examine how classic taxonomies would predict patient performance, accuracy and response time analyses were performed by comparing the three groups of participants with aphasia, RHD, and OCs. A 5 × 2 × 2 (Group × Congruency × Alteration) design was used. A gradient of severity in performance was predicted (OC < RHD < AA < BA < WA).

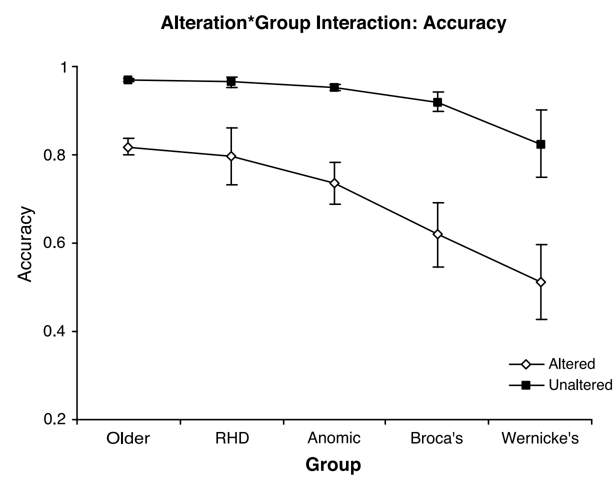
Accuracy. A total of 22 individuals with aphasia, 4 individuals with RHD, and 16 OCs were tested in the current experiment (see Table 1 for detailed patient information). There were main effects of both group, $F(4, 37) = 14.198$, $p = .0001$, $\eta_p^2 = .61$, and alteration, $F(1, 37) = 217.350$, $p = .0001$, $\eta_p^2 = .86$. Paired comparisons indicated that the OC, RHD, and AA groups did not differ significantly from one another (mean accuracy scores, collapsing over all factors, ranged from .843 to .894). BA and WA groups were significantly less accurate than all other groups and were significantly different from each other (OC > BA, $p = .0001$; OC > WA, $p = .0001$; RHD > BA, $p = .0074$; RHD > WA, $p = .0001$; AA > BA, $p = .0246$; AA > WA, $p = .0001$; BA > WA, $p = .0085$). As a whole, all participants demonstrated a significantly higher level of accuracy on unaltered items, as compared to altered stimuli. No main effect of congruency was noted, $F(1, 37) = .002$, $p = .9661$.

All two-way interactions were significant: Alteration × Group, $F(4, 37) = 5.682$, $p = .0011$; $\eta_p^2 = .38$; Congruency × Group, $F(4, 37) = 4.443$, $p = .0049$, $\eta_p^2 = .32$; and Congruency × Alteration, $F(1, 37) = 6.080$, $p = .0184$, $\eta_p^2 = .14$. Post hoc means comparisons were conducted to explore significant differences within and between groups for each interaction. We controlled for Type I errors by using the Tukey–Kramer honestly significant difference (HSD) method, via the JMPIN statistics software package. All significant differences reported used a p value of < .05.

In the unaltered condition (collapsing over congruency), we found that the WA group was significantly less accurate than all other groups, with the exception of the BA group. The BA group, however, did not perform significantly worse than any other group in this unaltered condition. As well, the OC, RHD, and AA groups did not differ from one another in the unaltered condition. In other words, performance in the unaltered condition corresponds to predictions based on classical aphasiology, with lexical comprehension deficits evident only in the WA group (see Figure 1).

In the altered condition (again, collapsing over congruency), a similar pattern of performance was noted for the WA group. They were significantly less accurate than all other groups, with the exception of the BA group. The BA group, however, performed significantly worse than both the OC and the RHD participants in this altered condition, but did not differ significantly from the AA group. No other group differences were noted in the altered condition (meaning that OC, RHD, and AA groups performed similarly in the altered condition). These results suggest that, in contrast with predictions based on classic aphasia taxonomies, patients with BA do show vulnerabilities in lexical comprehension that are not evident under standard testing conditions (see Figure 1).[3]

Figure 1. Interaction between the variables of alteration and group for patients and older controls on the lexical comprehension task. In the unaltered condition, a predictable pattern can be seen, with patients with Wernicke's aphasia (WA) making significantly more errors but patients with Broca's aphasia (BA) not differing significantly from any other group. In the altered condition, a gradient of diminished performance for all groups is now readily apparent. In particular, the BA group performed significantly worse than older controls and right-hemisphere-damaged patients (RHD), demonstrating vulnerabilities in lexical comprehension under nonoptimal conditions.



Further analyses were conducted in order to investigate within-group differences between the unaltered and altered conditions. These analyses showed that, for all participant groups, performance was significantly better on unaltered stimuli when compared to altered stimuli.

An additional within-group analysis looked at the difference between congruent and incongruent items. Both OC and WA performed better on congruent than

[3]It should be noted that the performance in the unaltered task may reflect some ceiling effects and thus not be sensitive in distinguishing between the groups. Furthermore, we caution against an interpretation that individuals with Broca's aphasia (or even other groups) may not be impaired in the unaltered condition, as the small sample size may have prevented us from detecting possible significant differences.

incongruent items, whereas RHD and BA showed the opposite pattern of performance (incongruent > congruent). AA showed no significant difference in accuracy between the congruency conditions. Hence, it appears that participants in both the OC and WA groups had a greater likelihood of pushing the match button, whereas participants in the RHD and BA groups were more likely to push the mismatch button.

Finally, the interaction of Congruency × Alteration on accuracy revealed significantly worse performance on both congruent and incongruent stimuli in the altered condition; however, congruent items were overall (collapsing over group) less accurately identified under acoustic degradation than incongruent items. In short, when listening conditions are degraded, it is easier to recognize a mismatch than a match. The three-way interaction of Congruency × Alteration × Group did not reach significance, $F(4, 37) = 2.108$, $p = .0994$.

Reaction times. Results for reaction times (for correct responses only) were different in several ways from the results reported for accuracy. Similar to that reported for the accuracy data, there were main effects of both group, $F(4, 37) = 5.278$, $p = .0018$, $\eta_p^2 = .36$, and alteration $F(1, 37) = 56.815$, $p = .0001$, $\eta_p^2 = .61$. There were, however, also significant main effects of congruency on reaction times, $F(4, 37) = 104.891$, $p = .0001$, $\eta_p^2 = .74$, unlike those observed for accuracy. To begin, the main effects of group were slightly different for the response time data than the accuracy data. As in the accuracy data, pairwise contrasts revealed no significant differences in processing speed between OCs, participants with RHD, and participants with AA. The BA group differed from all other groups except WA, demonstrating the longest latencies in response time of all groups (BA > OC, $p = .0002$; BA > RHD, $p = .0160$; BA > AA, $p = .0078$; BA = WA, $p = .6250$). The WA group differed significantly only in speed from the OCs (WA > control, $p = .0089$). In short, participants with WA showed minimal reductions in speed as compared to normal controls, and no differences from patients with mild deficits, while participants with BA demonstrated significant reductions in speed when compared to neurologically intact individuals and those with mild aphasia. Hence, our reaction time data suggest that participants with WA did not show deficits in speed of processing as significant as those shown by them for accuracy of processing. Participants with BA, however, showed a significant delay in speed of processing when compared to other groups with better accuracy performance. These results may be reflective of a speed–accuracy trade-off in these two groups of patients (WA and BA) in which those with WA may be fast in responding to single words but not very accurate, whereas those with BA may be accurate but show their deficits in the slowness of their response.

Main effects of alteration, when collapsing over participants and congruency, were similar to those noted in the accuracy data. Overall, participants responded more quickly to unaltered items as compared to altered items (F and p values reported above). The main effect of congruency, $F(1, 37) = 104.891$, $p = .0001$, $\eta_p^2 = .74$, when collapsing over groups and alteration, revealed faster response times for congruent (matching or indicating "yes") versus incongruent items (mismatch or indicating "no").

None of the two-way interactions reached significance: congruency by group, $F(4, 37) = 1.063$, $p = .3885$; alteration by group, $F(4, 37) = 1.368$, $p = .2639$; and congruency by alteration, $F(1, 37) = .002$, $p = .9641$. However, the three-way interaction was significant: congruency by alteration by group, $F(4, 37) = 5.377$, $p = .0016$; $\eta_p^2 = .37$. Between-group comparisons were conducted within each condition in order to explore this interaction. In the congruent/unaltered, the only significant finding was a decrease in processing speed for BA as compared to the OC. This again may be reflective of the difficulty that BA have with making an indication of a match. In the incongruent/unaltered condition, the same disparity was found between BA and OC; WA were also significantly slower than OC. As mentioned above, the longer latencies in the incongruent condition for the WA may be reflective of their greater propensity to indicate that the items are matched. Thus, they need a greater amount of time to accurately identify the mismatch. In the congruent/altered condition, there were again significant differences in the processing speed of the BA and WA when compared to OC participants. This time, however, BA were also significantly slower than AA. This appears to be reflective of the increased difficulty in performing this task under degraded conditions when the comprehension deficits are more severe. No other group differences were noted. Finally, in the incongruent/altered (arguably the most difficult condition), there were no significant RT differences between any of the groups.

Only Individuals With Aphasia

So far, we have underscored the continuous nature of lexical comprehension skills within and across our patient groups, but we have treated the patient factor itself as a discrete variable, relying on classical taxonomies. To further demonstrate this continuous symptom space, we performed multiple regression analysis to see if independent language measures could better characterize patient performance on our lexical comprehension measure. Within the group with aphasia, we wanted to determine whether performance on this picture–word verification task, as measured by the

Table 2. Regression analyses using subtests of the Western Aphasia Battery as predictors of accuracy and reaction time (RT).

Subtest	Total		Comprehension		Fluency	
	%	*p*	%	*p*	%	*p*
Congruent Accuracy	37.6	.011*	6.7	.169	15.8	.041*
Incongruent Accuracy	52.3	.001*	43.3	.001*	29.8	.003*
Altered Accuracy	49.7	.001*	44.5	.001*	0.5	.674
Unaltered Accuracy	50.7	.001*	50.5	.000*	11.6	.047*
Congruent RT	64.5	.000*	51.8	.000*	1	.806
Incongruent RT	52.4	.001*	48.3	.000*	9	.550
Altered RT	45.5	.003*	38.2	.002*	0	.990
Unaltered RT	68.6	.000*	61.6	.000*	6	.560
Accuracy total	61.1	.000*	59.6	.000*	4.4	.157
RT total p	58.4	.000*	50.8	.000*	6.6	.8

*$p < .05$.

two dependent variables, accuracy and RT, would display significant correlations with aphasia subscale scores as calculated from the WAB, ignoring the taxonomies themselves and collapsing across groups with aphasia. Multiple regression analyses were conducted, with two subtest scores on the WAB (Comprehension and Fluency) serving as predictors of accuracy and reaction time (see Table 2). These two subtests were chosen as they are the subtests that best distinguish the performance between BA and WA. In looking carefully at the WAB scores on these two subtests, we found a range in performance within the groups that was highly varied (BA Comprehension ranged from 5.0 to 9.3; BA Fluency ranged from 0 to 4; WA Comprehension ranged from 2.1 to 6.9; WA Fluency ranged from 7.0 to 9.0). Consequently, we believe that the continuous measures will yield more meaningful results than discrete groupings that lack sensitivity.

When accuracy was treated as the dependent variable, the total amount of variance accounted for by the two predictors (WAB Comprehension and WAB Fluency) was 61.1% (p = .000). Thus, WAB Comprehension and WAB Fluency together predicted accurate performance to a large extent. The comprehension measure was the only variable to make a unique contribution to the overall variance in this model, accounting for 59.6% of the variance (p = .000). In looking over conditions, however, a different pattern of contributions emerged. In the congruent condition (collapsing over alteration) the fluency measure was the only one to make a unique contribution to the overall variance. There was a unique contribution of both fluency and comprehension to the overall variance in both the incongruent (collapsing over alteration) and the unaltered condition (collapsing over congruency). Finally, comprehension made a unique contribution to the overall variance in the altered condition (see Table 2).

When reaction time was treated as the dependent variable, the total amount of variance accounted for by the two predictors was also significant at 58.4% (p = .000) (see Table 2). For reaction time, however, there was only a unique contribution of comprehension to the total variance of the model, accounting for 50.8% of the variance (p = .000). Unlike the findings for the accuracy correlation, comprehension was the only factor (of the two) that made unique contributions in all conditions. The fluency measure did not reach significance in any of the conditions (see Table 2).

In summary, it appears that comprehension is the variable making a unique contribution to the overall variance of both accuracy and reaction time. When we examine the separate conditions, however, we see that fluency does have a unique contribution to the variance of some measures, but only in accuracy. Fluency has a unique contribution to the accuracy measure for all conditions except when conditions are degraded. It appears that when conditions are degraded, patients with higher levels of fluency have a more difficult time accurately identifying a match between the sound and pictures. On the other hand, when the conditions are optimal, participants rely on both intact comprehension and greater fluency to determine that the sound and picture do not match. With respect to reaction times, it appears that this dependent measure is primarily driven by the integrity of the participants' comprehension. Hence, individuals with higher comprehension scores exhibit faster (or numerically lower) reaction times. In short, it appears that different predictors are driving the different conditions within the accuracy data than are driving the conditions in the reaction time data: (a) the comprehension variable is the only one to make a unique contribution to the reaction time data, and (b) both comprehension and fluency make unique contributions to various conditions in the accuracy data, suggesting that accuracy and reaction time are influenced by the integrity of different aspects of processing (i.e., comprehension vs. fluency).

Discussion

In this study, we set out to investigate the nature of lexical comprehension in individuals with aphasia. Although there is an abundance of evidence (dating as far back as the time that the syndromes were originally defined) that details the continuous nature of the symptom space observed in individuals with aphasia, we continue to describe and characterize linguistic behaviors as being "spared" or "impaired" in the individual with aphasia. And, while in many instances this may be a convenient shorthand, it may also limit or mislead discussions concerning language abilities in aphasia. For example, although we have discovered over the past 25 years that individuals with BA do show deficits at the lexical level (e.g., impairments in lexical priming), there is rarely disagreement over the integrity of single-word comprehension. Given that we believe that all structures are vulnerable to processing failures, irrespective of lesion site, we predicted that we could take a function that is seemingly intact in one population of patients and show that by taxing general cognitive resources we could change the performance. We selected single-word comprehension because it is a behavior that is widely held to be intact in individuals with BA. We used a combination of exogenous stressors (low-pass filtering and time compression) to look at the integrity of the lexical comprehension system in left-hemisphere damaged patients with aphasia, individuals with RHD without aphasia, and healthy OCs. Our primary results can be summarized as follows.

First, in analyses of accuracy comparing patient groups and controls, performance under unaltered conditions replicated classical findings using standard aphasia batteries: Individuals with WA were significantly impaired in single-word comprehension, whereas none of the other groups (including those with BA) differed from controls. This finding is not surprising, as it mirrors the normative data collected in almost every standardized test of aphasia and it is the basis for our definitions of the individual aphasia syndromes. As we cautioned earlier, however, the small sample size may have contributed to the lack of significant results seen in the group of individuals with BA. The pattern of performance, however, suggests that any differences that may have been detected with a larger sample size would have only provided further support for the claim that this function is not completely spared in this population.

The diminished performance of individuals with BA was, however, clearly detected in the altered condition. Although individuals with WA were still the most impaired group, patients with BA performed significantly below OCs on this simple lexical comprehension task. Hence, stimulus degradations related to those that are encountered in everyday life reveal vulnerabilities in people with BA that are not evident under optimal testing conditions. In fact, although there was a lack of significant results for the other groups tested, there was a trend for decreased performance for all groups of participants. This suggests that all individuals are susceptible to decrements in performance in the linguistic domain when nonlinguistic resources (e.g., perception and speed of processing) are taxed. This diminished performance is more marked, however, in individuals with BA than in individuals with AA, in individuals with RHD, or in neurologically intact individuals. This suggests that while individuals with BA may look spared under optimal processing conditions, they may be just above a certain threshold necessary to complete the task. Once this threshold is crossed (e.g., by increasing the processing demands), decrements in performance can be observed.

Second, the reaction time findings largely shadowed findings for accuracy (e.g., altered slower than unaltered). However, we also picked up patterns in reaction time that were not evident in accuracy. In particular, patients with WA (despite their low performance) were relatively fast (though slower than OCs), whereas patients with BA were slower than all the other groups. There are a number of possible explanations for these reaction time results. For one, it may be that as the hallmark symptom of WA is impaired auditory comprehension, they may not be able to perform the task accurately no matter how much time they take. Thus, they respond with a relatively more normal reaction time (as compared to individuals with BA), as the added time to process will not lead to greater success on the accuracy measure. It may be, however, that they suffer from an inability to inhibit themselves. This is evident in the hyper-fluent output profiles of individuals with WA. This inability to inhibit the response would also lead to more normal response times, but it may be at the root of the deficits in accuracy as opposed to the other way around. Either way, it appears that there may be a speed–accuracy trade-off in this population. There also appears to be evidence for a speed–accuracy trade-off in the group of individuals with BA. As noted above, under optimal conditions individuals with BA show high levels of performance in accuracy on this task; however, they show significantly slower reaction times as compared to all other groups. It may be that in searching for the accurate response, they are delayed in responding. On the other hand, it may be that they suffer from delays in reaction time, which buy them the time necessary to accurately perform the task. In contrast to the profile described for individuals with WA, the delays in reaction time observed in individuals with BA may be due to underactivation of lexical items. Evidence in support of this claim has been discussed in the lexical priming literature (see the introduction for references), and is also evident in the hypo-fluent patterns of output observed in individuals with BA.

Third, we switched from between-group analyses that assume discrete taxonomies to within-group regression analyses for all patients with aphasia that treat the same aphasia subtests used to construct taxonomies as continuous predictors. In overall analyses on accuracy, we found that the two WAB subscales accounted for 61.1% of the variance, with a significant unique contribution from the WAB Comprehension scale to the overall accuracy measure. The WAB Fluency measure, however, did make a unique contribution in all but one of the conditions (altered) in the accuracy measure. WAB Fluency was also the only variable to make a unique contribution to the congruency condition of the accuracy measure. In other words, intact fluency leads to greater accuracy when the task requires a match between items. This suggests that participants may be relying on intact fluency to generate names for objects when they see them, and making a match between the generated label and the sound perceived over the speakers. WAB Comprehension scores also made unique contributions to all but one of the conditions (congruency) in the accuracy measure. WAB Comprehension was also the only variable to make a unique contribution to the altered condition of the accuracy measure. Here, it appears that participants rely on intact auditory comprehension to assist them in accurately processing information in noise. So, in comparison to making a match, when participants are listening in noise, they may not be relying on a generated label to match to, but rather may be focusing on comprehending the distorted sound signal that they are hearing. One reason why the Fluency scale may not be contributing to a unique variance in the overall accuracy measure is because high levels of fluency are observed in all groups except individuals with BA: This includes normal OCs, individuals with AA, individuals with RHD, and individuals with WA. Whereas individuals with WA are on the higher end of the scale on the WAB Fluency measure, their fluency is qualitatively very different than that of the other groups with high levels of fluency. Thus, greater fluency is not always reflective of greater function. The influence of higher scores and "good" fluency observed in the normal controls, individuals with RHD, and individuals with AA may be offset by the higher scores but "bad" fluency observed in individuals with WA. The issue is the same for reaction time. The overall reaction time analysis yielded significant unique contributions only from the WAB auditory comprehension measure. This was, however, also true for the individual conditions as well. The WAB Fluency scale did not make a unique contribution to any of the RT data; however, the WAB Comprehension scale made a unique contribution to all conditions of the RT measure. It is important to note that the range in performance on the Comprehension subtest of the WAB showed significant overlap between the groups. The group of individuals with BA showed a range of performance on the WAB Comprehension subscale from 5 to 9.3, whereas the group of individuals with WA showed a range from 2.1 to 6.9. Five of the 9 individuals with BA and 4 of the 5 individuals with WA had WAB Comprehension scores between 5 and 6.9. This suggests that grouping patients into categories may be very misleading if we presume that these patients dissociate in particular domains. In fact, the majority of patients in this study had Comprehension scores that were in the region of overlap between the two populations of patients. In analyzing the data in this way, we allow patients to be viewed more appropriately in a continuous symptom space. This allows us to see not only differences between groups, but similarities between individuals in particular domains of processing.

Conclusions

There is mounting evidence from the sciences as a whole that aging is a biological process that can be defined, measured, described, and manipulated (Arking, 1991). A century-long investigation into age-related changes on brain and behaviors reveals differences in arousal, attention, memory, and perception functions in older adults. This process of changes has been claimed to be not only rooted in endogenous factors (i.e., biological and genetic makeups; Yu & Yang, 1996) but also impacted by exogenous factors (i.e., environmental influences; Arking, 1991). The effects of these changes on higher level cognitive processing (such as language processing) cannot always be easily predicted or mapped out. For example, some older individuals have more trouble than younger individuals when processing in noisy environments despite hearing sensitivity thresholds that are within normal clinical limits on a standard measurement screening (Willott, 1991). Findings such as these point to multiple factors at play in producing the unexpected diminished performance that do not add up in a predictable way. As the elderly are dealing with varying degrees of changes in memory, attention, perception, and so forth, it is difficult to determine precisely how processing will break down, if it will at all. This processing terrain becomes even more difficult to map out when we add brain injury to the equation. However, we very readily describe the linguistic behaviors observed in aphasia as being "spared" or "impaired" despite our adequate knowledge that these structures, or the processing of them, are not discrete in healthy older people. But, if we argue nonetheless that the state of the neurologically intact older individual is to be the benchmark for intact functioning, we should use their performance as the measure by which to judge intactness. Hence, when we claim that a function remains intact in individuals with aphasia, we should expect to see performance that is equivalent to that of the neurologically intact adult individual. The results presented here, however, highlight the need to use caution in assuming that functions are easily distinguishable as intact or impaired. It appears more accurate to consider that all tasks have varying processing loads that require different degrees of resources and may thus be differentially impacted by diminished general cognitive resources and degraded environmental conditions, leading to graded performance in real-world situations.

Taken together, these results support a redefinition of the symptom space observed in individuals with aphasia as being continuous rather than discrete. We are not suggesting a radical departure from classic teaching, but rather aim to highlight some subtle differences that are less obvious (or in the worst case, ignored) in the traditional approach. In uncovering vulnerabilities in the accurate and efficient processing of individuals with BA at the single-word level, we have provided evidence against the classical claim that single-word comprehension is intact in patients with nonfluent BA. Performance appears to be highly dependent on general cognitive resources, as well as vulnerable to reductions in those resources that may arise from either endogenous or exogenous factors. Although we found that the classic taxonomies may hold under optimal conditions, we know that these conditions are rarely present in everyday processing life. More often, we are processing in noisy environments with competing stimuli that require added focus of attention to filter the appropriate speech signal from the noise. And, as we can see, this task is harder for the individual with aphasia than for the healthy, older adult, despite seemingly even playing fields on some levels. In processing under these typical conditions we can see a more accurate picture of the nature of the symptom space that we are faced with when we begin to map out our course of treatment. These issues have importance both theoretically and clinically. We owe it to our patients to pursue their study on both grounds if we are to provide the best services to our clients.

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